FuelCell Energy

Ultra-Clean, Efficient, Reliable Power

High Temperature (> 400º C) Fuel Cells

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Ultra-Clean | Efficient | Reliable Power

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Fuel Cell Technologies

	MW - Class	Sub-MW - Class		Micro CHP	Mobile
Technology	**Carbonate (MCFC)**	**Phosphoric Acid (PAFC)**	**Solid Oxide (SOFC)**	**PEM/SOFC**	**Polymer Electrolyte Membrane (PEM)**
System Size Range	300 kW – 3.7 MW	400 kW	> 50kW	< 10 kW	5 - 100 kW
Typical Application	Utilities, Commercial, Industrial - Baseload	Commercial Buildings - Baseload	Industrial and Commercial Buildings - Baseload	Residential & Small Commercial	Transportation
Fuel	Natural Gas, Directed Biogas	Natural Gas	Natural Gas	Natural Gas	Hydrogen
Advantages	High Efficiency & CHP	CHP	High Efficiency & CHP	CHP	Load Following & Low Temperature
Electrical Efficiency	47% - 60%	40% - 42%	50% - 60%	25% - 40%	25% - 35%
Combined Heat & Power (CHP)	Steam, Hot Water, Chilling & Bottoming Cycles	Hot Water, Chilling	Steam, Hot Water, Chilling & Bottoming Cycles	Suitable for Facility Heating	No *(which is desirable for transportation)*
					
					

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Moten Carbonate Fuel Cell (MCFC)

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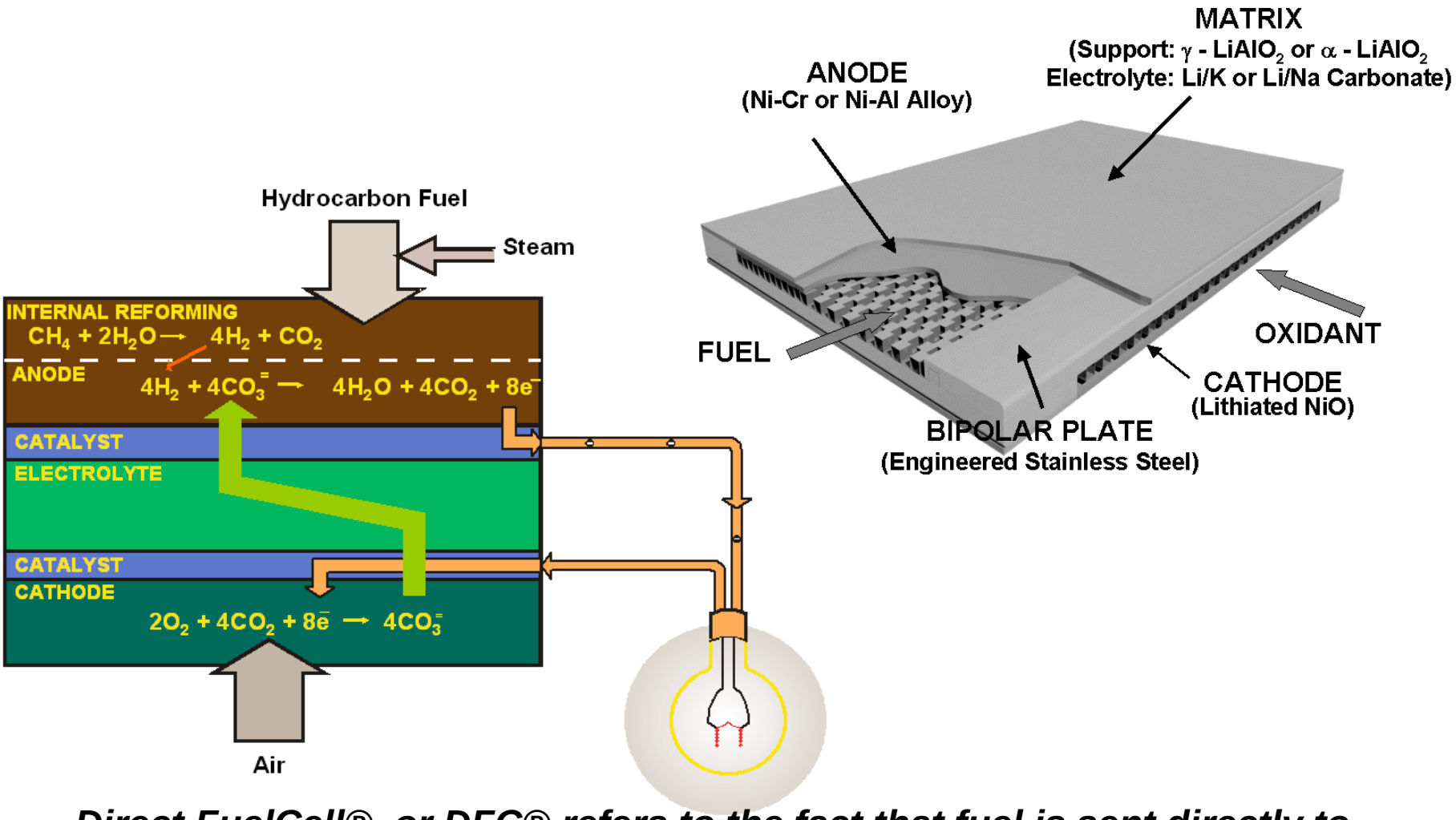
MCFC-Based Direct FuelCell



Direct FuelCell®, or DFC® refers to the fact that fuel is sent directly to the fuel cell stack, without an external reformation step

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MCFC Power Plants

Individual fuel cell
&
350 kW fuel cell stack

Four-Stack Module
1.4 megawatts

Completed module
1.4 megawatts

1.4 MW DFC1500®
- *Utilizes one module*
- *Adequate to power 1,400 homes*

2.8 MW DFC3000®
- *Utilizes two modules*
- *Adequate to power 2,800 homes*

59MW fuel cell park

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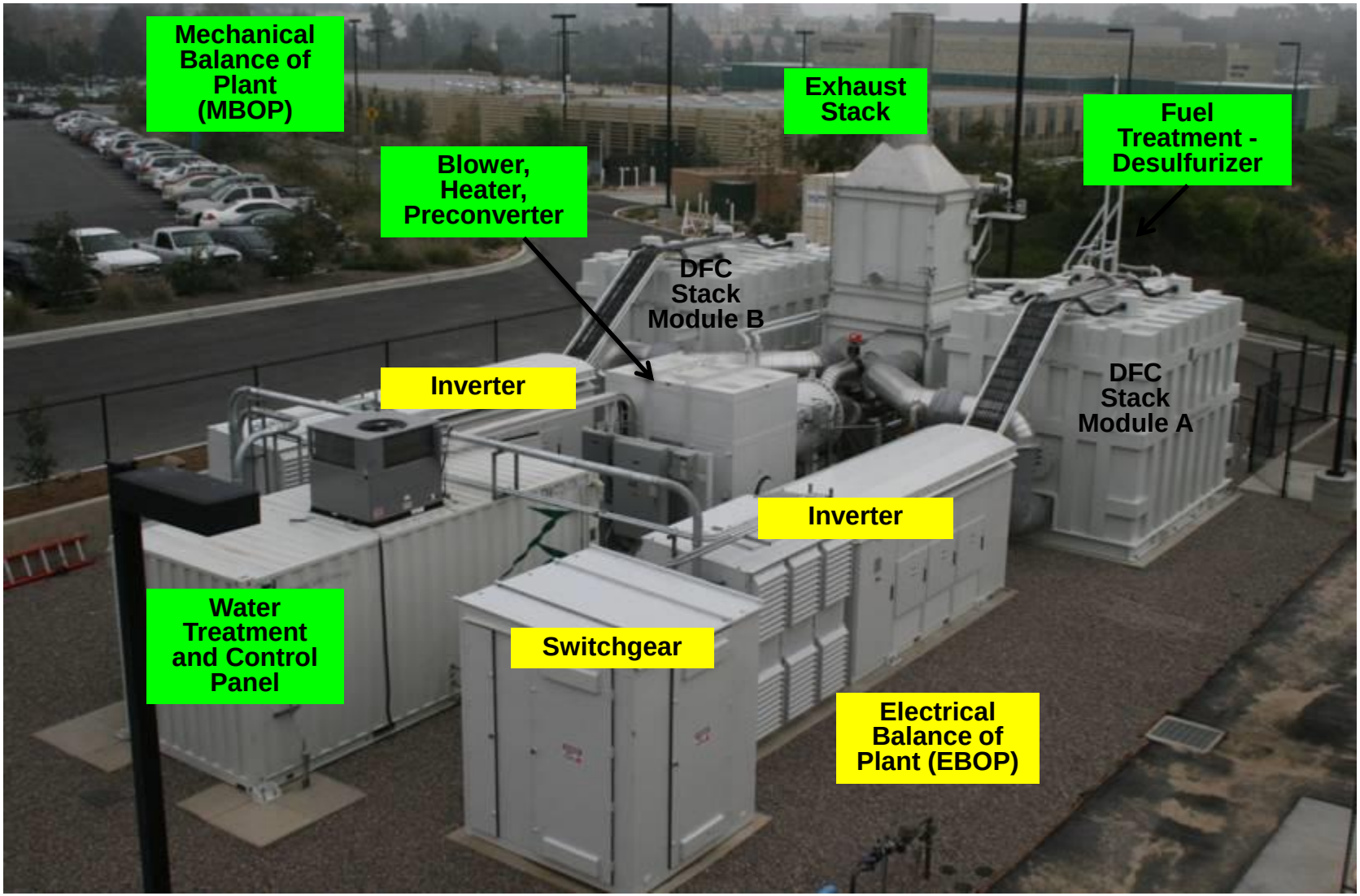
Powerplant Subsystems



2.8 MW DFC3000 Power Plant

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Two Types of Applications

On-site Power *(Behind the Meter)*

Typical Project sizes 1.4 – 11.2 MW

- **Affordable & Clean energy**
  - High efficiency drives savings
  - CHP reduces costs and improves customer's carbon footprint
  - Virtual lack of pollutants benefits public health
- **Supports energy security** (micro-grid)

Electric Grid Support

Typical Project Sizes 5.6 – 60 MW

- **Cost effective baseload power**
  - when/where needed *(i.e. next to existing sub-stations)*
  - Avoids transmission cost and permitting / reduces congestion
- **Enhances grid resiliency**
- **Supports economic development & renewable portfolio standards**

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Natural Gas & Renewable Markets

Natural Gas

- Electric Utilities & IPPs
- Education & Healthcare
- Gas Transmission
- Industrial
- Commercial, Data Centers
- Government
- Oil Production & Refining

Renewable Biogas

- Wastewater
- Food & Beverage Processing
- Agriculture
- Landfill Gas

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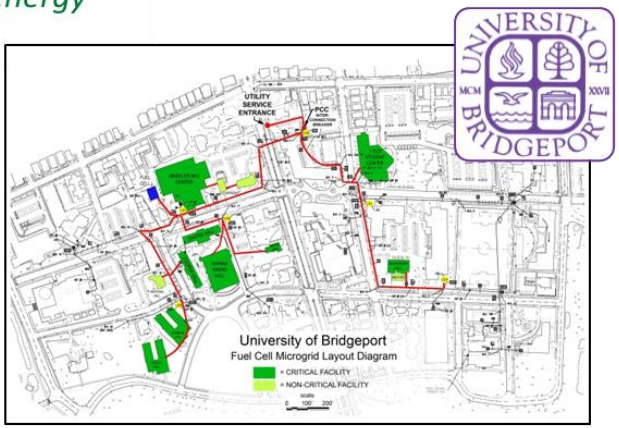
Fuel cell micro-grids

Fuel cells only:

Fuel cells can be the sole energy source for a micro-grid



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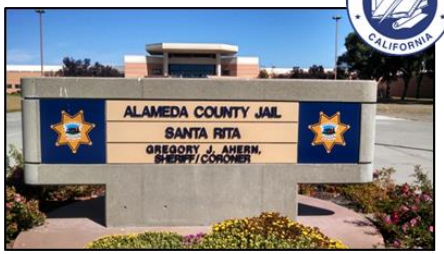
Turnkey solution includes:
designing and modeling the micro-grid
&
building, operating and maintaining the fuel cell power plant

Combined with other power generation systems:

Fuel cell micro-grids can operate in tandem with other on-site power generation technologies



"A fuel cell powered by directed biogas is the cornerstone of the micro-grid operation."

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Fuel Cell Plants in Bridgeport, CT

University Micro-grid with CHP

Fuel cell / Solar integration

Grid support benefitting urban redevelopment

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Solid Oxide Fuel Cell (SOFC)

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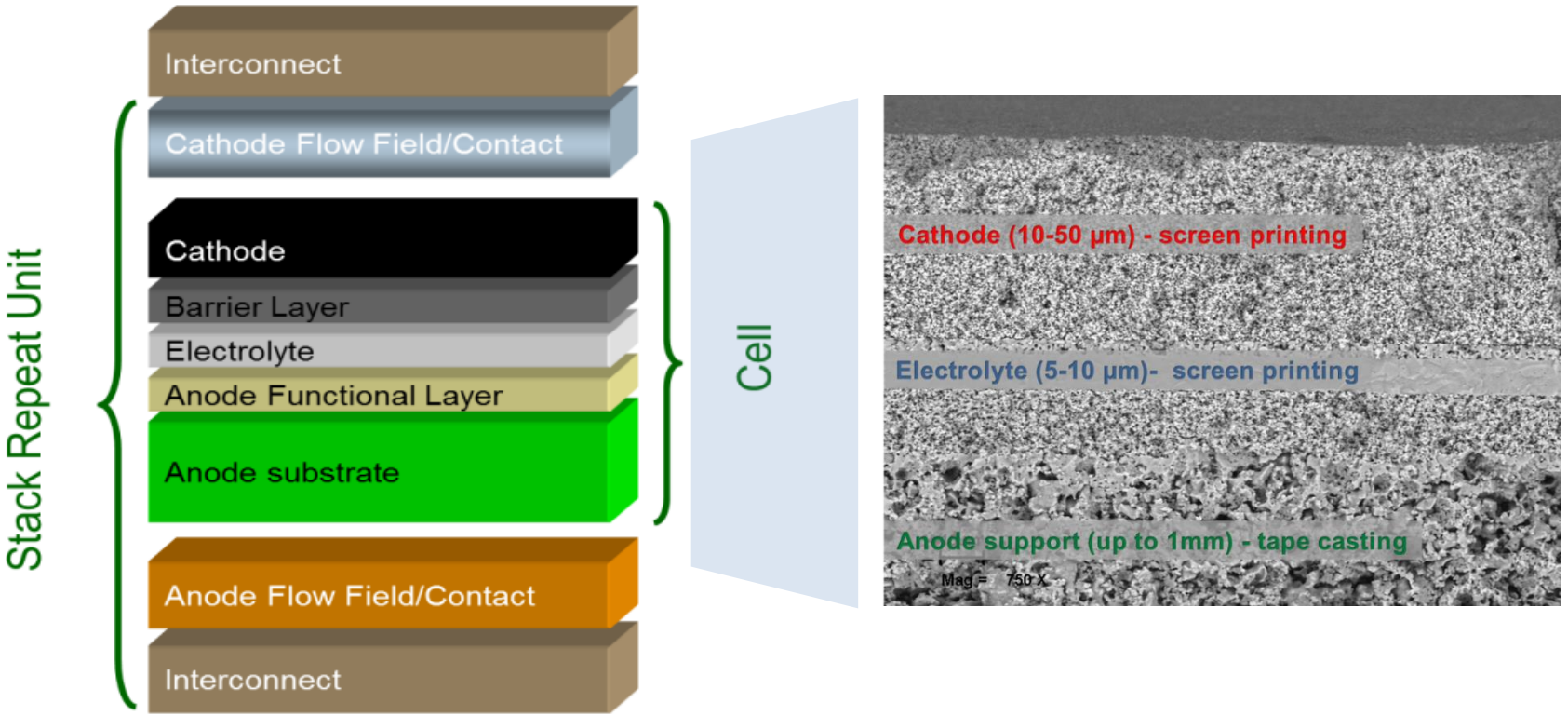
Anode-Supported SOFC Technology Overview



Component	Materials	Thickness	Porosity	Process
Anode	Ni/YSZ	0.3 - 0.6 mm	~ 40%	Tape casting
Electrolyte	YSZ	5 - 10 µm	< 5%	Screen printing
Cathode	Conducting ceramic	10 - 50 µm	~ 30%	Screen printing

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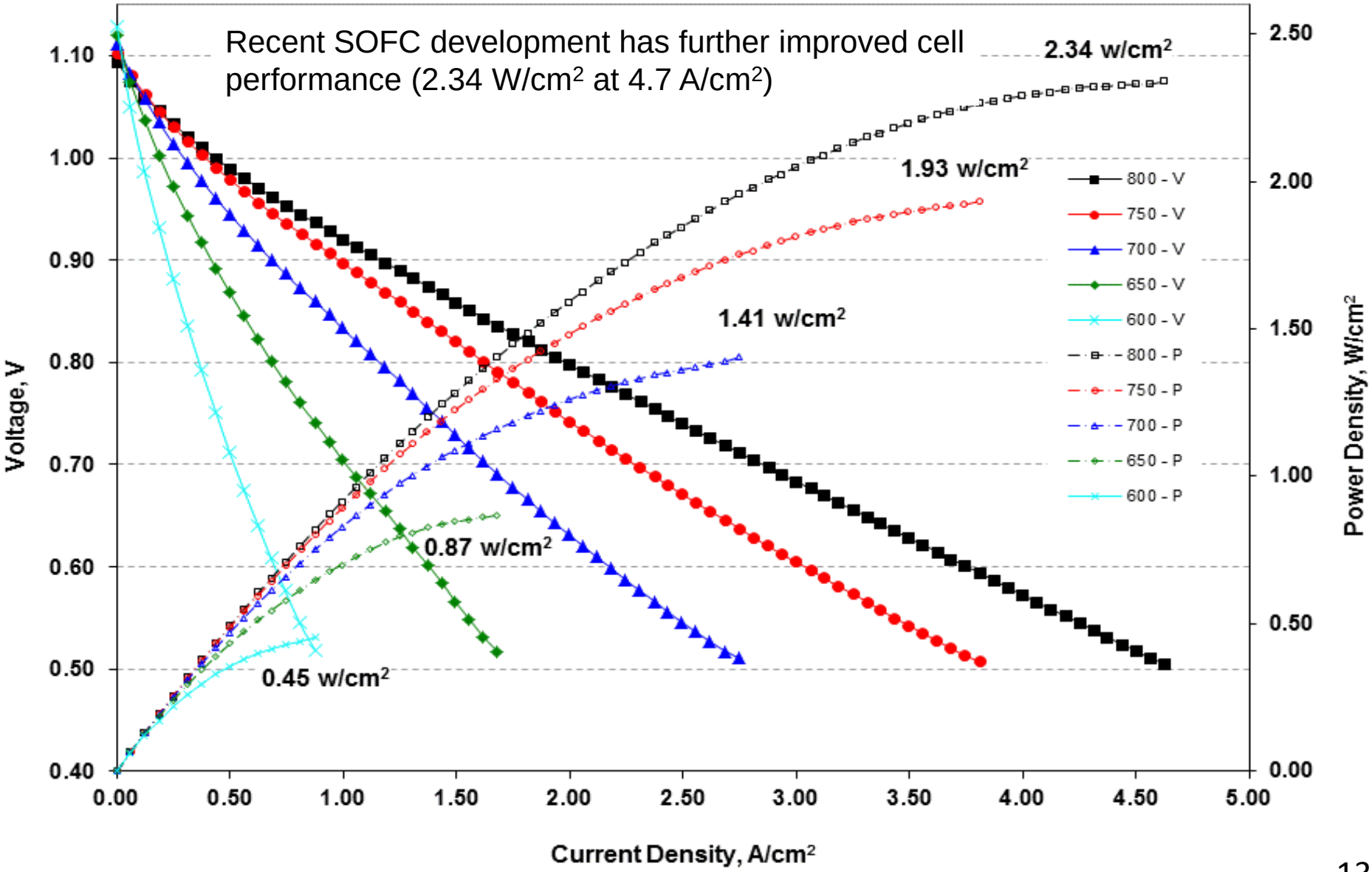
Recent SOFC Performance



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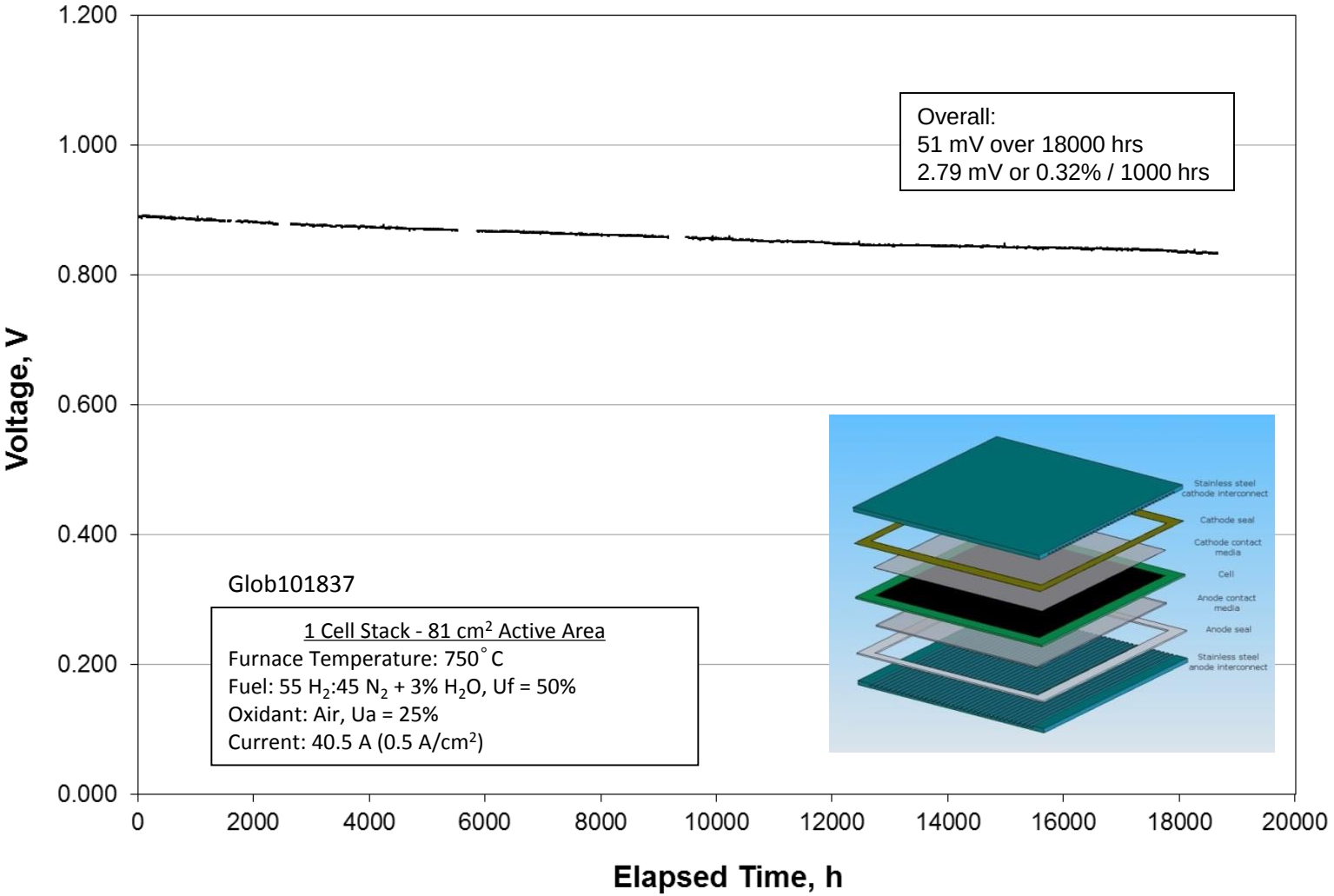
Long-term Performance



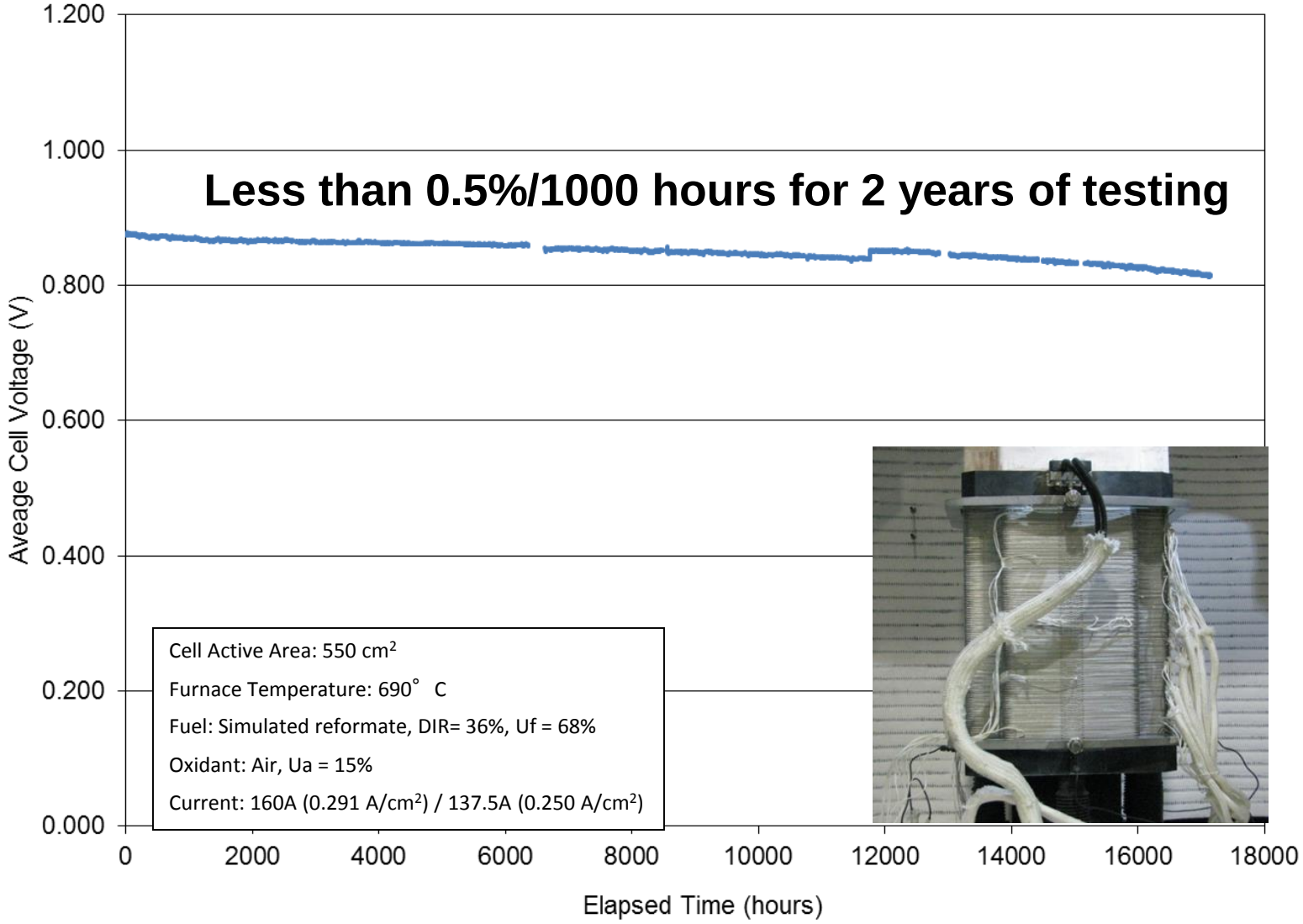
→ Long-term cell endurance was verified in >2 years of operation with a 0.32%/1000h performance degradation

Baseline Stack Building Block

Operating Conditions	
Fuel Utilization	68%
Air Utilization	15 – 40%
In-Stack Reforming	25 – 70%
Stack Current	160 A (291 mA/cm^2)
Gross DC Electrical Power	~16 kW

Cell Size	25 x 25 cm^2
Active Area	550 cm^2
Number of Cells	120

Baseline Stack with Improved Reliability



GT058139-0002

50 kW System Performance Summary

	Design	**Actual**
DC Power (gross)	55.1 kW	**56.2 kW**
Natural Gas Fuel Flow	4.9 scfm	**5.03 scfm**
Fuel Energy (LHV)	80.8 kW	**82.7 kW**
Water Consumption	0	**0**
Gross Module DC Efficiency (LHV)	68.2%	**67.9%**
Total on Load Time	1500 hrs	**>1500 hrs**
Overall Stack Performance Degradation	<1% per 1000 hrs	**<1% per 1000 hrs**

- 50kW proof of concept for SOFC system design at factory testing facility

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Next Generation Sub-MW Class Power Plant

- System is designed with the capability to achieve 200 kW net ac
- It houses (2) 100kW SOFC Module Power Blocks (MPB)
- Skid sized as standard ISO 20’ x 8’ shipping container
- Thermally integrated modules enable compact system design
- 2.5X higher power density than 50kW Plant:
  - 50kW = 2.23 ft^2/kW
  - 200kW = 0.88 ft^2/kW
- Stack Module and BOP factory assembled & shipped as a single skid
- Capable of operation with a single module

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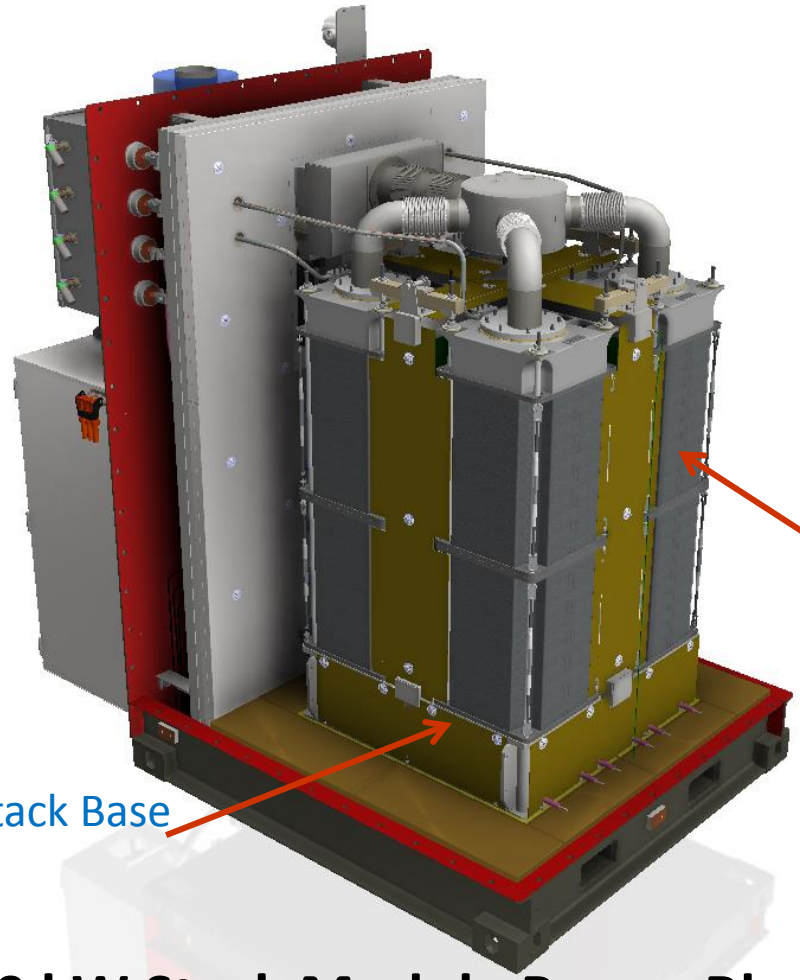
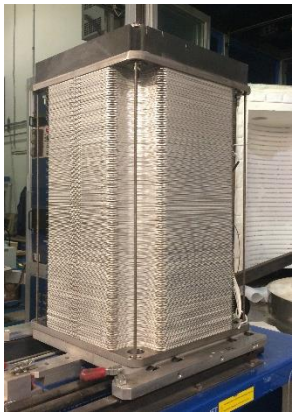
100 kW SOFC Stack Module



100 kW Stack Module Power Block



Baseline Stack (120-cells)

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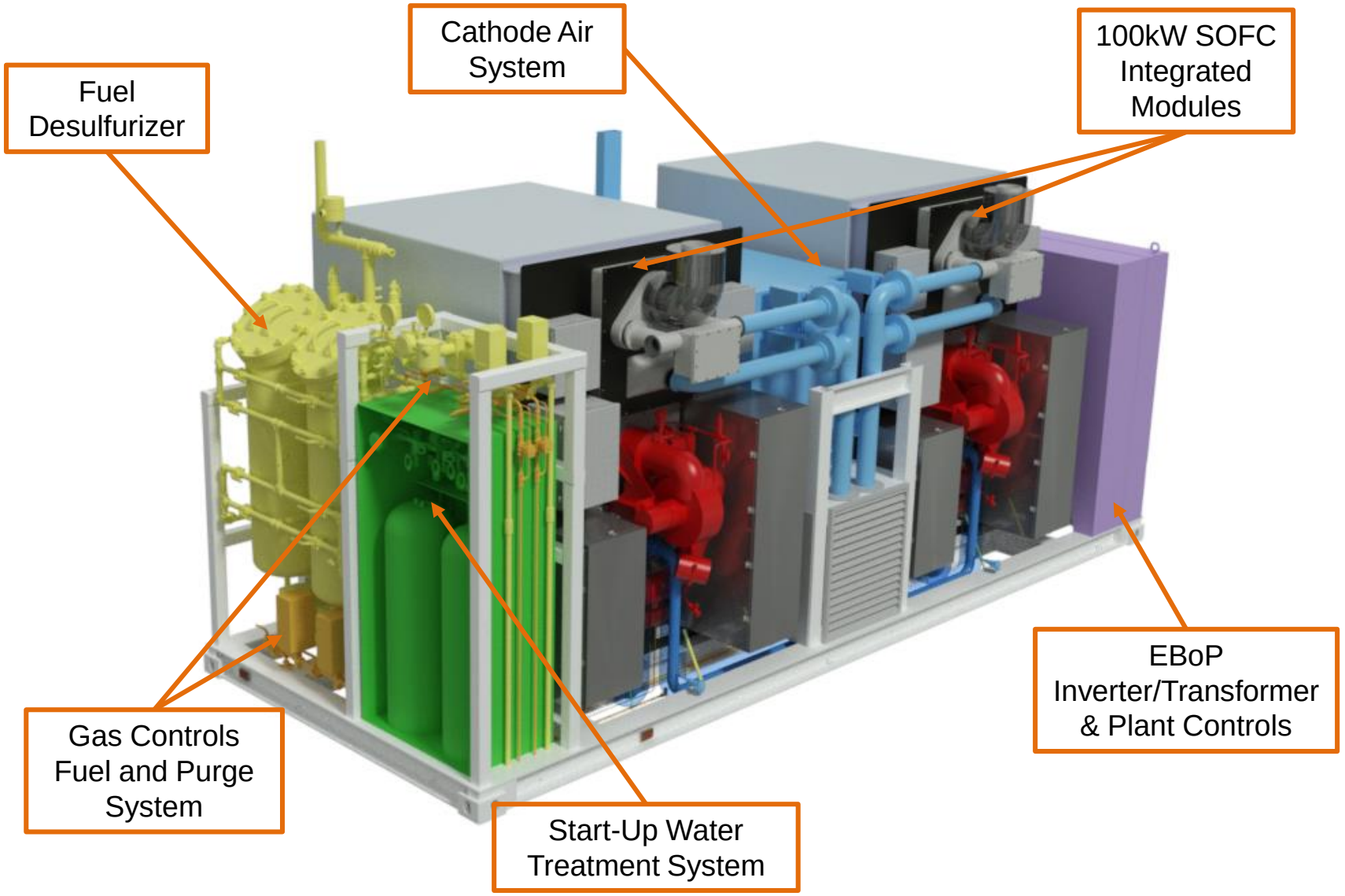
200kW SOFC Power System Layout



- **Includes (2) 100kW SOFC Module Power Blocks (MPB) designed to operate independently**
- **Factory assembled & shipped as a standard ISO 20' x 8' container**

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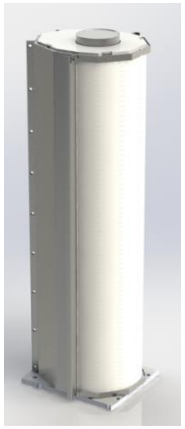
200 kW SOFC System Performance

200 kW SOFC System Performance Summary

SOFC Gross Power	Normal Operating Conditions		Rated Power	
DC Power	**225.0**	**kW**	**244.0**	**kW**
Energy & Water Input				
Natural Gas Fuel Flow	19.7	scfm	21.6	scfm
Fuel Energy (LHV)	323.2	kW	355.5	kW
Water Consumption @ Full Power	0	gpm	0	gpm
Consumed Power				
AC Power Consumption	10.8	kW	12.5	kW
Inverter Loss	11.3	kW	12.2	kW
Total Parasitic Power Consumption	**22.0**	**kW**	**24.7**	**kW**
Net Generation &Waste Heat Availability				
SOFC Plant Net AC Output	**203.0**	**kW**	**219.3**	**kW**
Available Heat for CHP (to 48.9°C)	**84.7**	**kW**	**90.8**	**kW**
Exhaust Temperature - nominal	**370**	**°C**	**370**	**°C**
Efficiency				
Electrical Efficiency (LHV)	**62.8**	**%**	**61.7**	**%**
Total CHP Efficiency (LHV) to 48.9°C	**89.0**	**%**	**87.2**	**%**

Innovative SOFC Concepts

Current Pre-Commercial Integrated Manifold (PCI) Stack

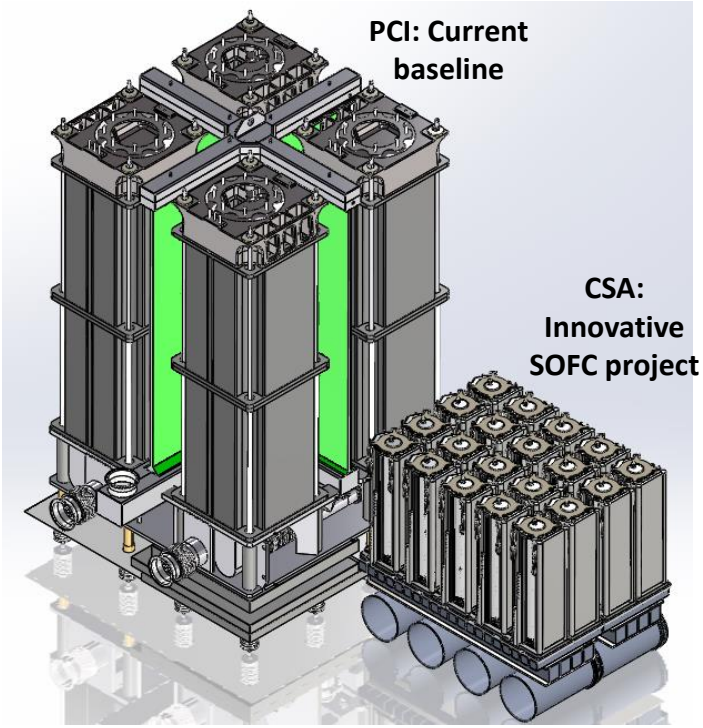


Compact SOFC Architecture (CSA) Stack with ~10-fold Increase in W/kg Power Density

- **Objective**

  Develop an innovative stack design enabling significant reduction in stack cost relative to baseline stack design (PCI)

- **Approach**
  - Thinned components to reduce stack material content
  - Use of same cell, interconnect and coating materials validated in the PCI platform
  - Increased cell count per stack and simplified end plates
  - Designed for automated assembly
  - Simplified and fewer discrete components
  - Optimized thermal and flow design to control temperature variations



Comparison of 100 kW Stack Module Based on Current PCI Stack Design (Left) and CSA Stack Design (Right)